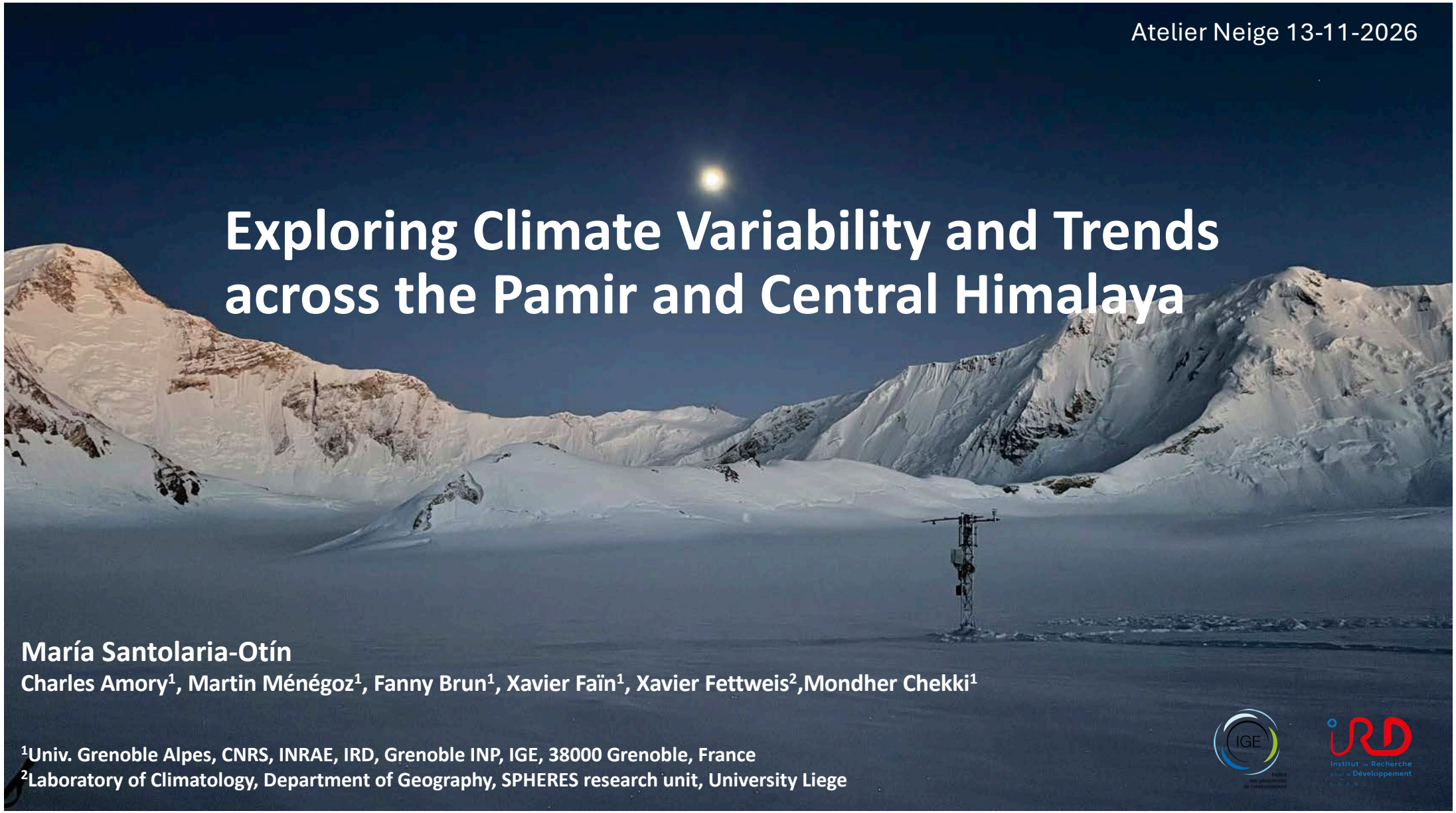


Atelier Neige 13-11-2026

Exploring Climate Variability and Trends across the Pamir and Central Himalaya

María Santolaria-Otín

Charles Amory[1], Martin Ménégoz[1], Fanny Brun[1], Xavier Faïn[1], Xavier Fettweis[2],Mondher Chekki[1]

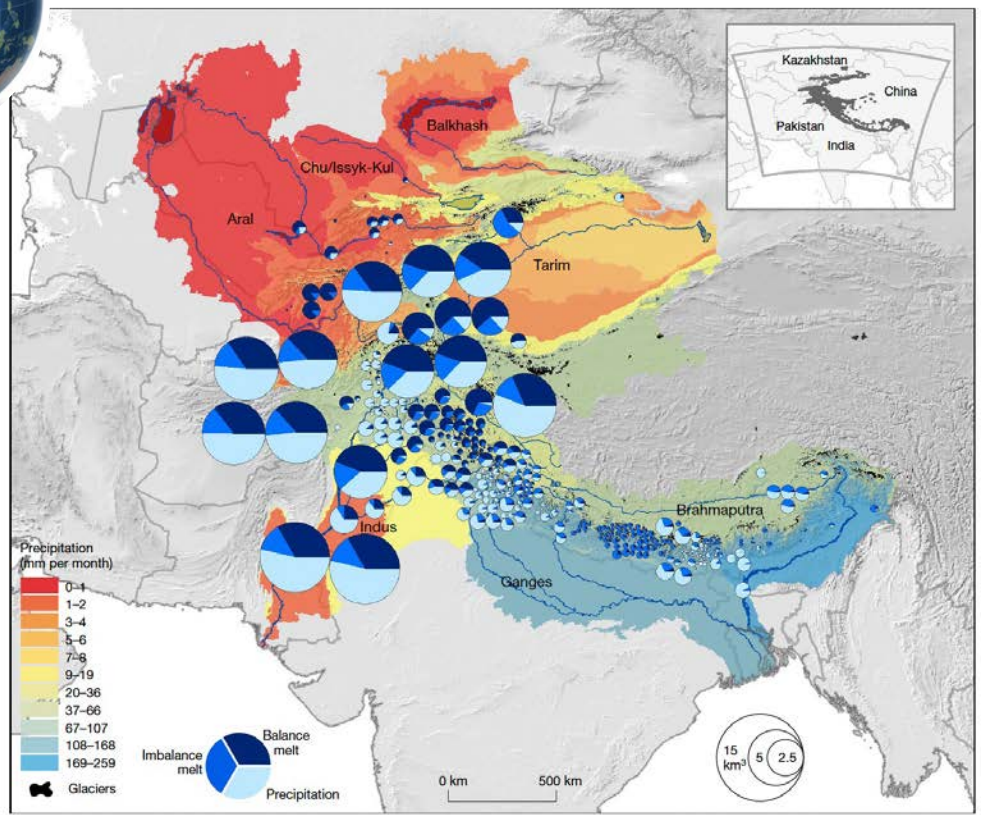
[1]Univ. Grenoble Alpes, CNRS, INRAE, IRD, Grenoble INP, IGE, 38000 Grenoble, France

[2]Laboratory of Climatology, Department of Geography, SPHERES research unit, University Liege

The Water Tower of Asia

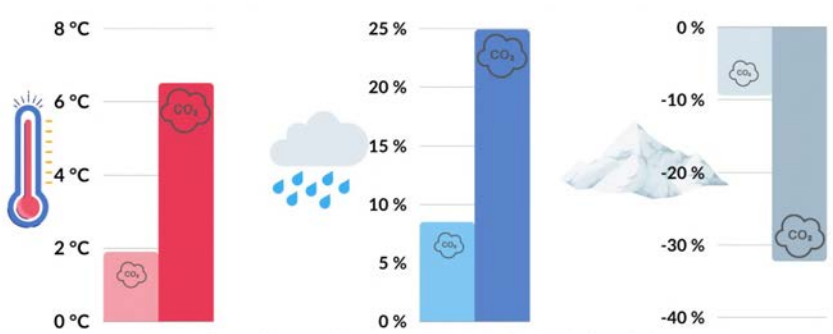


DROUGHT YEAR

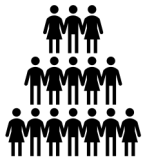


Pritchard 2019, Nature

Low and high emission scenario
Δ(2081–2100) – (1995–2014)

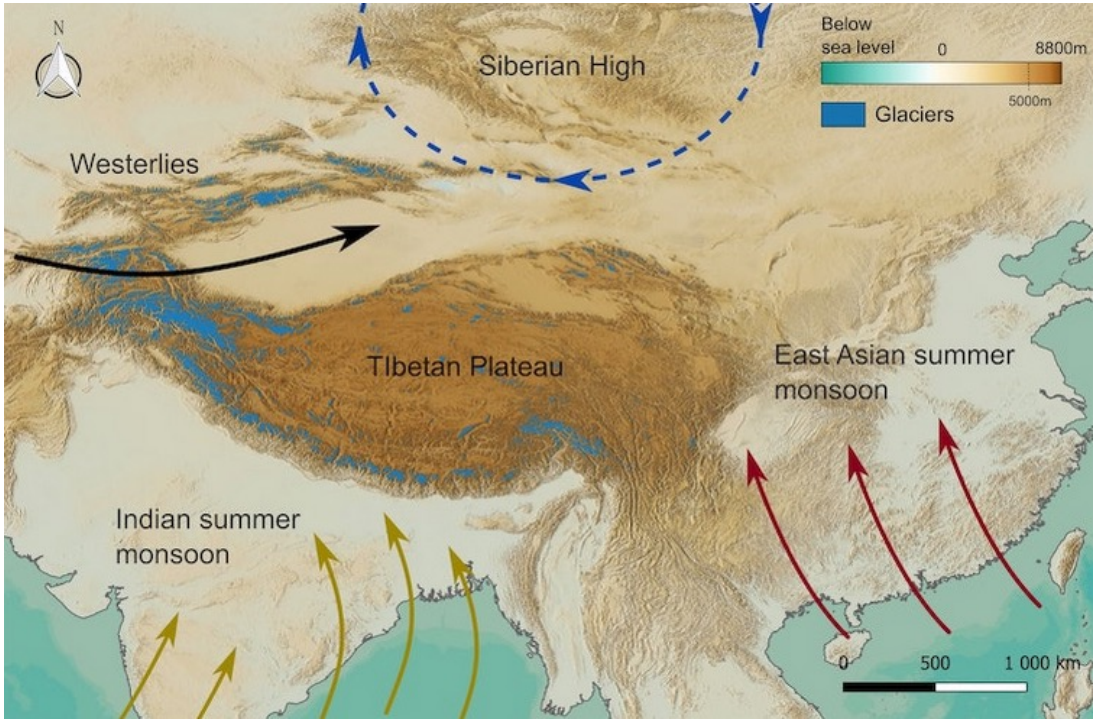


Lalande et al. 2021, ESD



~ 800 million people

Challenges in High Mountain Asia:



Ménégoz et al., 2021 :*Glacier in the high mountains of Asia in the face of climate change, www.encyclopedie-environnement.org*

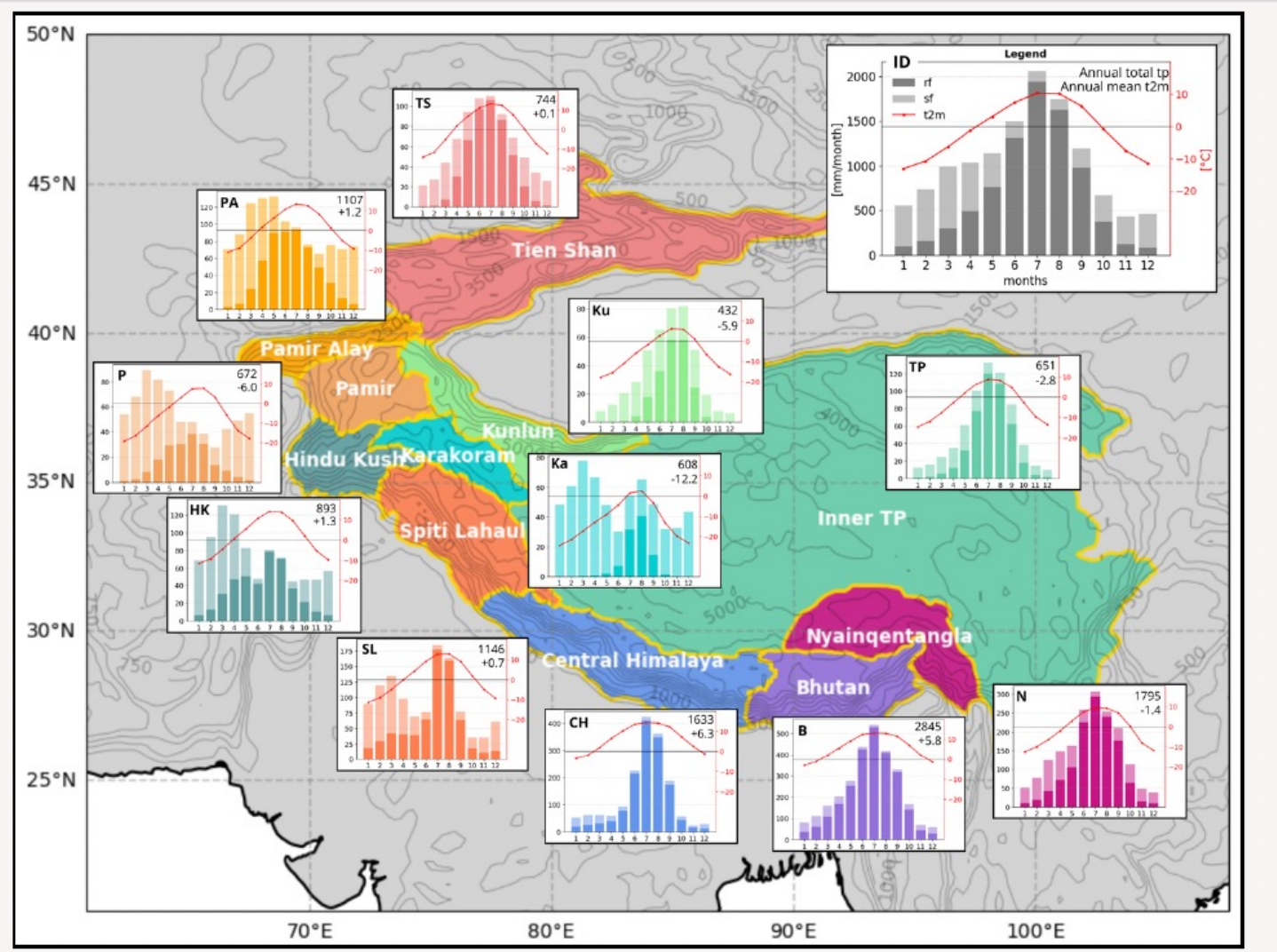
Scarcity of long-term and spatially dense observations.

Steep and complex topography with strong elevation gradients.

Contrasting climate regimes

Heterogeneous climate regimes

Annual cycle of
temperature and precipitation
ERA5 1960-2019

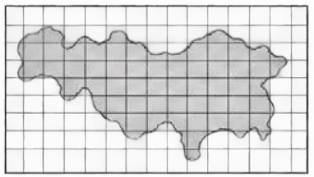


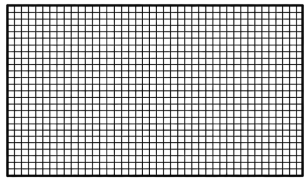
Brice et al, *in prep*:
'*Temporary multi-decadal growing glaciers in High Mountain Asia overwhelmed by unavoidable long-term retreat*'

Climate modelling in HMA: strengths and limitations across scales

Global climate models	Regional climate models	Km-scale
100-250 km ✗	7- 15 km ✓	<10km ✓
Topography very smoothed ✗	Topography quite realistic ~	Topography realistic ✓
>100 years ✓	1950-present (forcing) ✓	Few years, events ✗
Large ensemble (LE) ✓	1-few realisations ~	1 realisation ✗
Global ✓	Specific domains ✗	Small specific domains ✗







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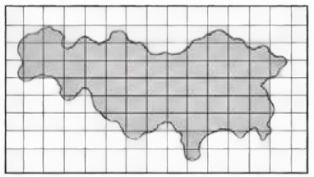
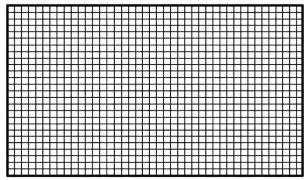
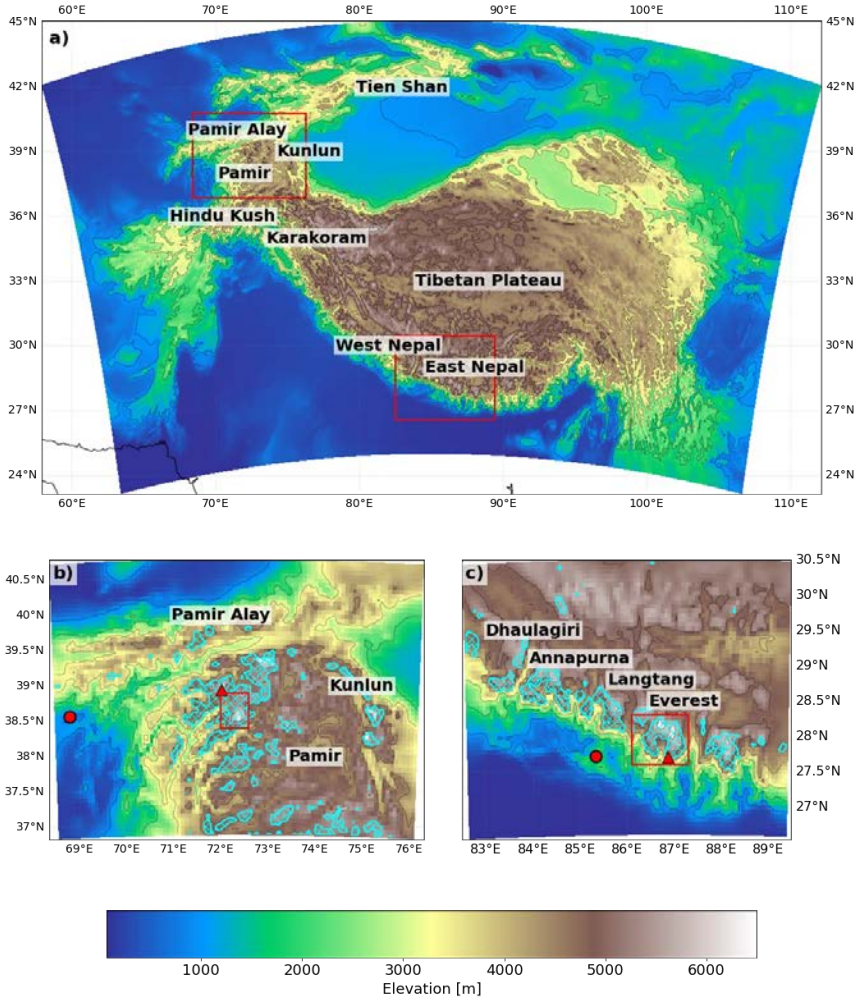




Different climate questions require different modelling approaches

Modèle Atmosphérique Régional

[Gallée,1995, Ménégoz et al. 2013, Fettweis et al. 2017, Beaumet et al. 2020, Castellanos et al. 2025]



Santolaria-Otín et al. *in review at GMD*

Simulations 7kmx7km (1950-2025)

Modèle Atmosphérique Régional

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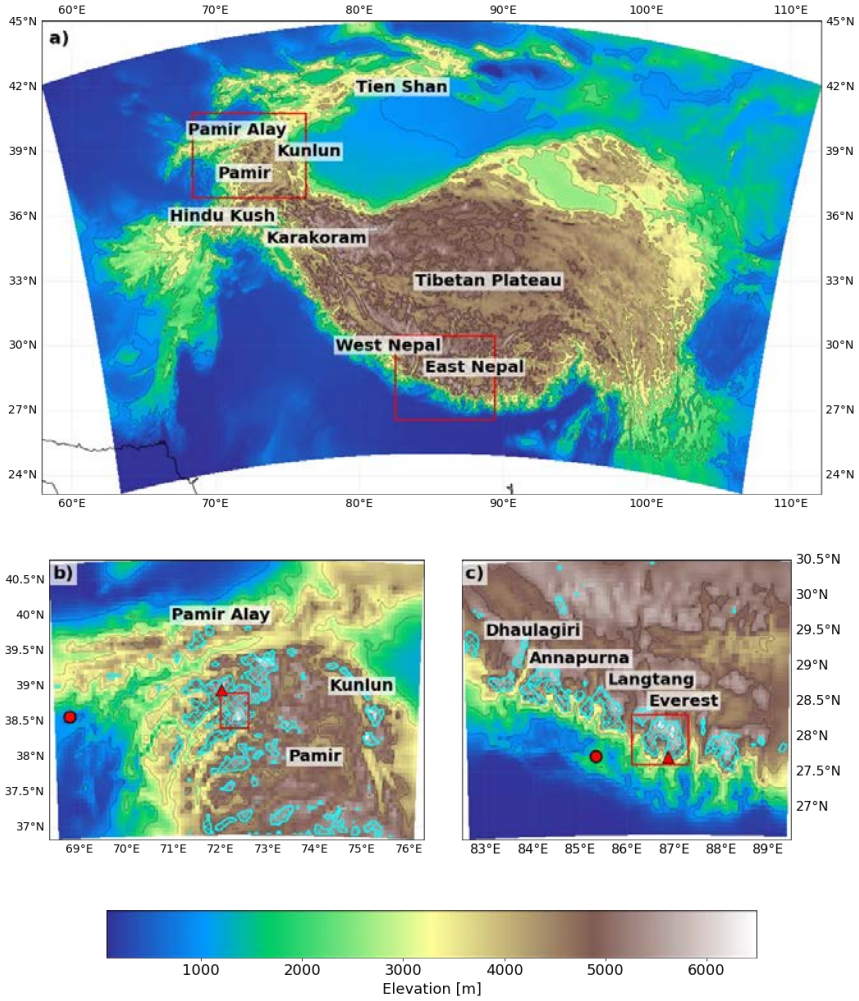


Santolaria-Otín et al. *in review at GMD*

Simulations 7kmx7km (1950-2025)

<u>As we are at the 'atelier-neige' …</u>

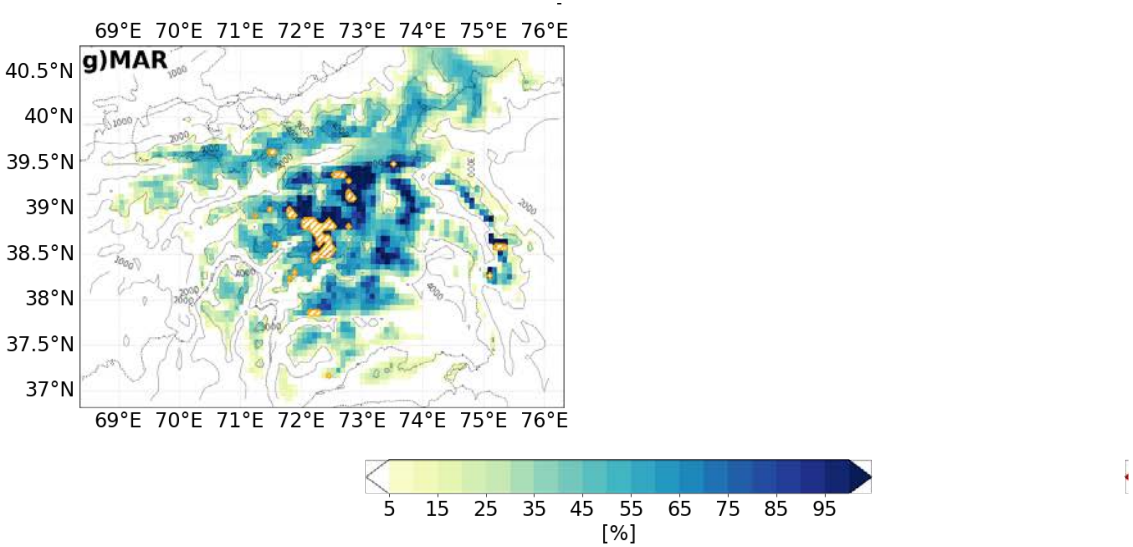
Q1: Snow in MAR vs observation

Q2: Snow trends

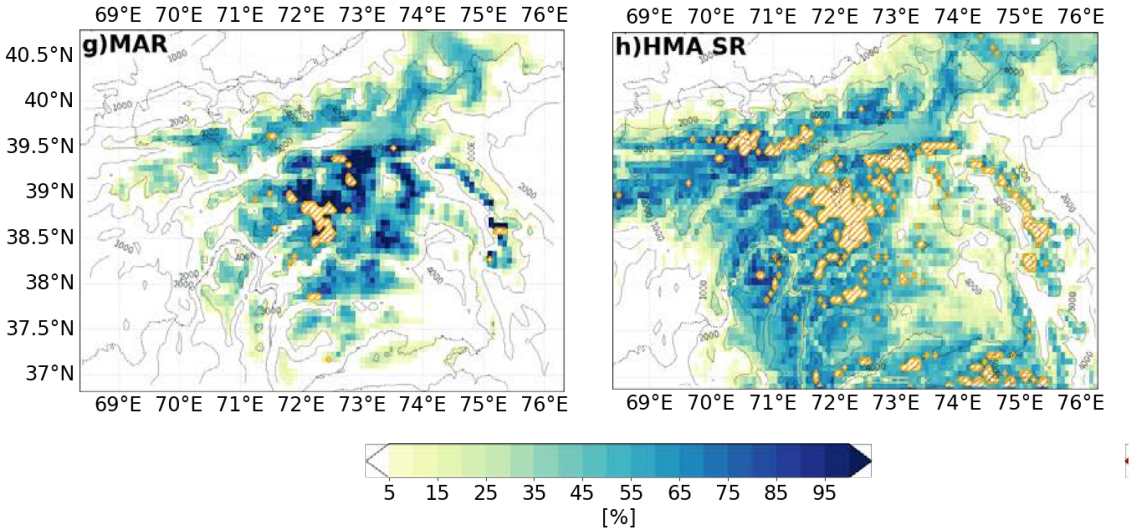
Grided snow data

	Variable	Resolution	Perdiod	Reference
Satellite-based				
HMA SR V1	Snow depth	16 ’’ (~500m)	1999–2017	Liu et al. 2021
ESA CCI v2.0	Snow cover	0.05° × 0.05°	1979–2022	Naegeli et al. 2021
Reanalysis				
HAR v2	t2m,pre,snd	10 km × 10 km	1980-2023	Wang et al. 2021
ERA5-Land	t2m,pre,snd	0.1° × 0.1°	1950-present	Muñoz et al. 2021
Model				
MAR v3	t2m,pre,snd	7 km × 7 km	1950-2025	Gallée, 1995

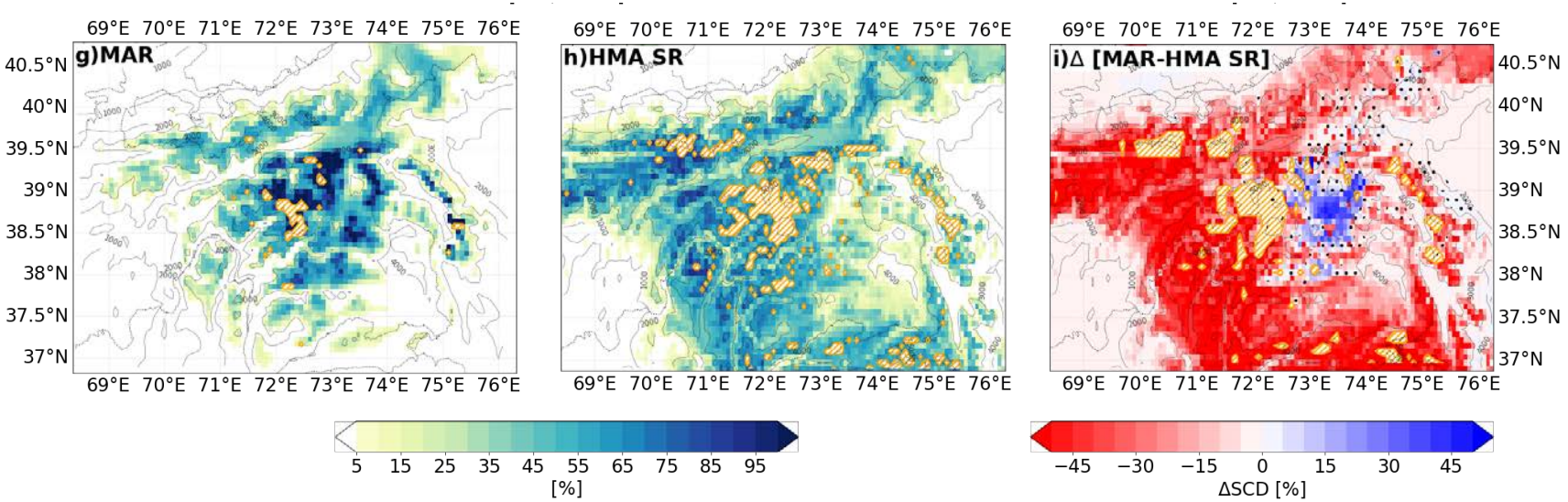
Snow cover duration (2000-2017)



Snow cover duration (2000-2017)



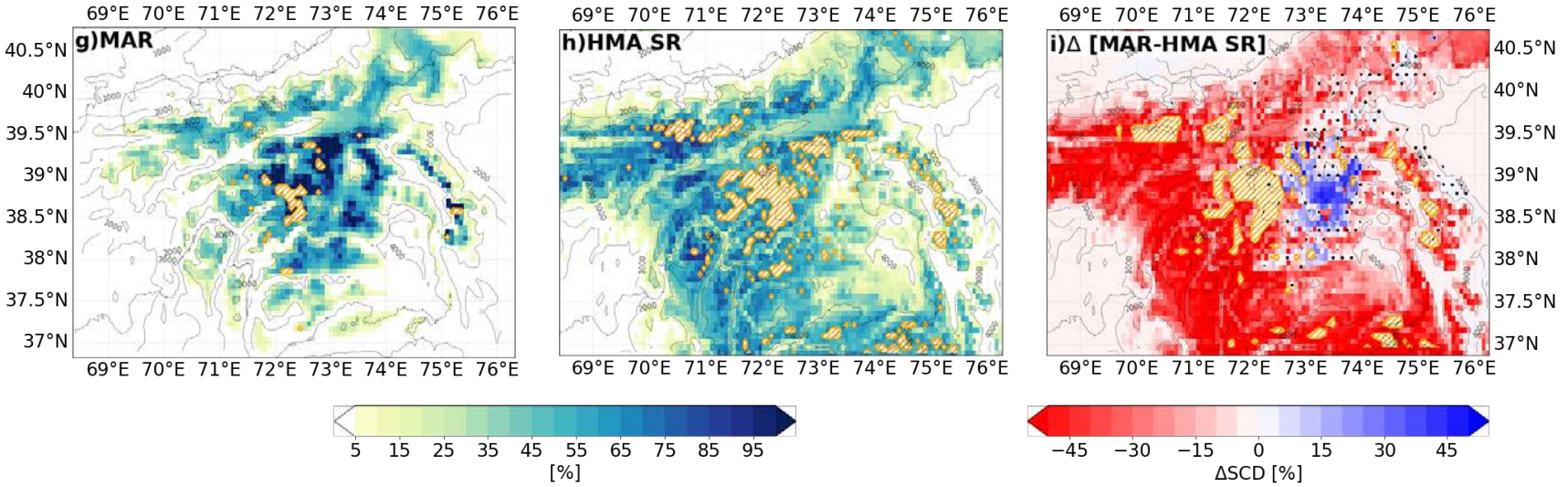
Snow cover duration (2000-2017)

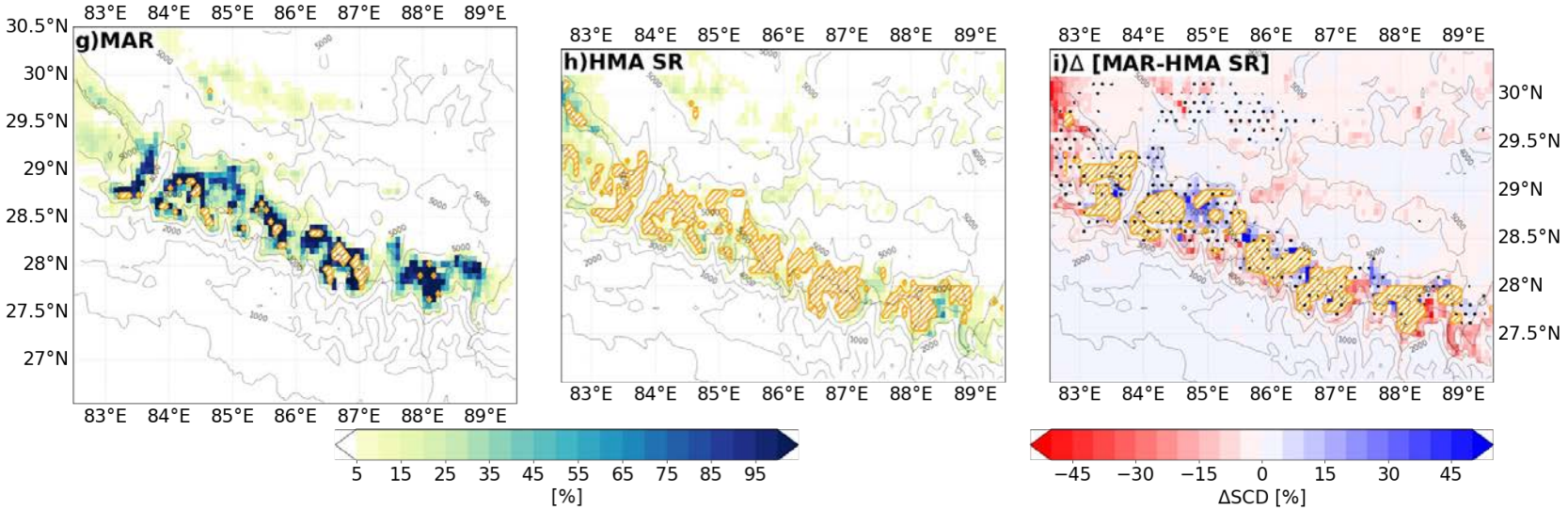


Overestimation of snow at high elevation

Underestimation of snow at mid-to-low elevation

Snow cover duration (2000-2017)

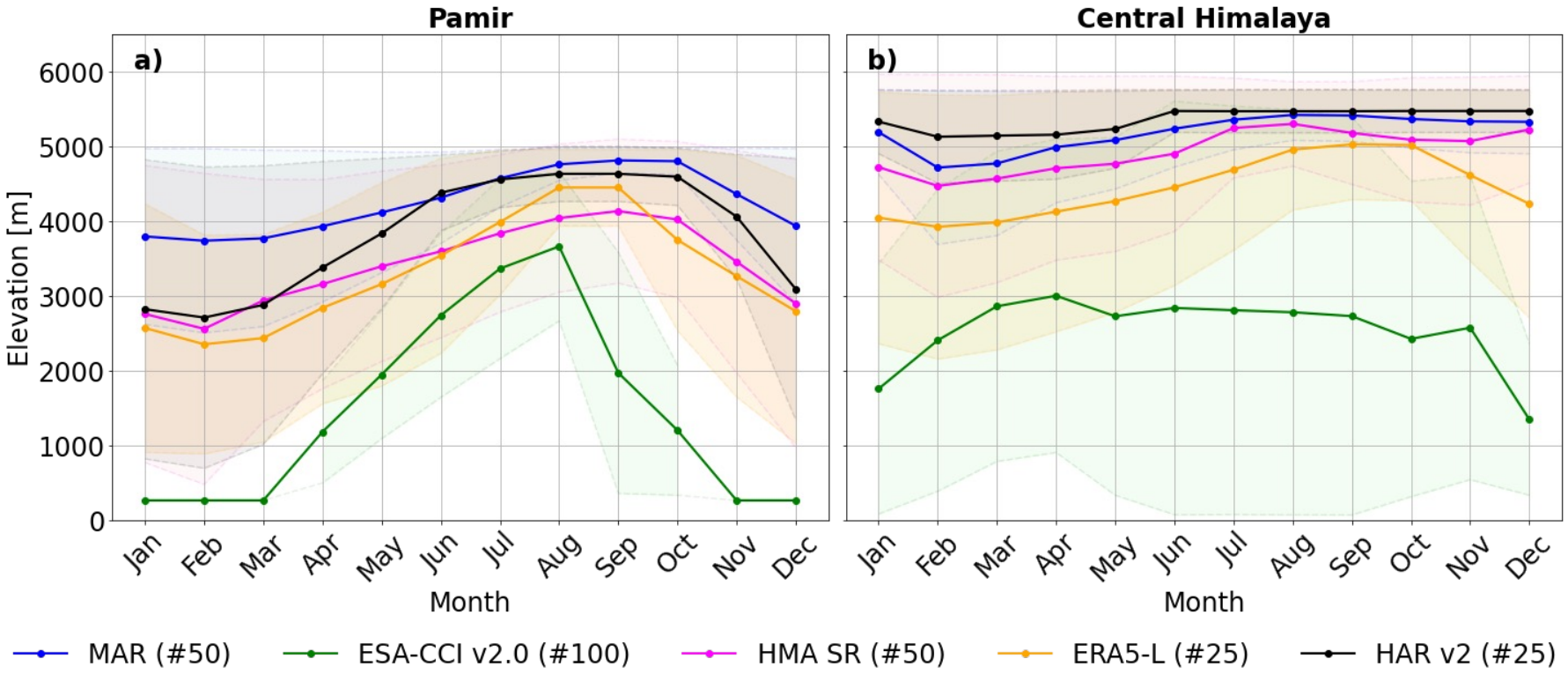




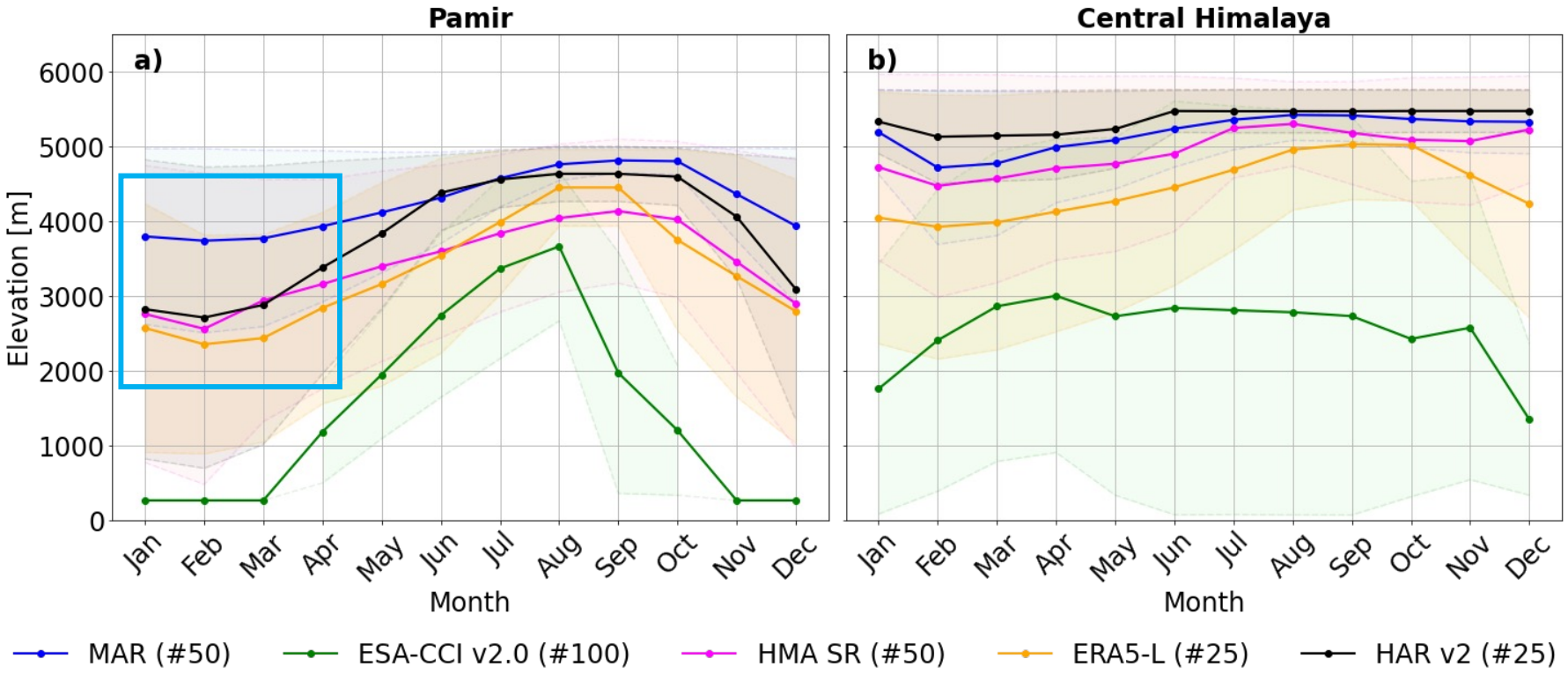
Overestimation of snow at high elevation

Underestimation of snow at mid-to-low elevation

Annual cycle of snowline (2000-2017)



Annual cycle of snowline (2000-2017)



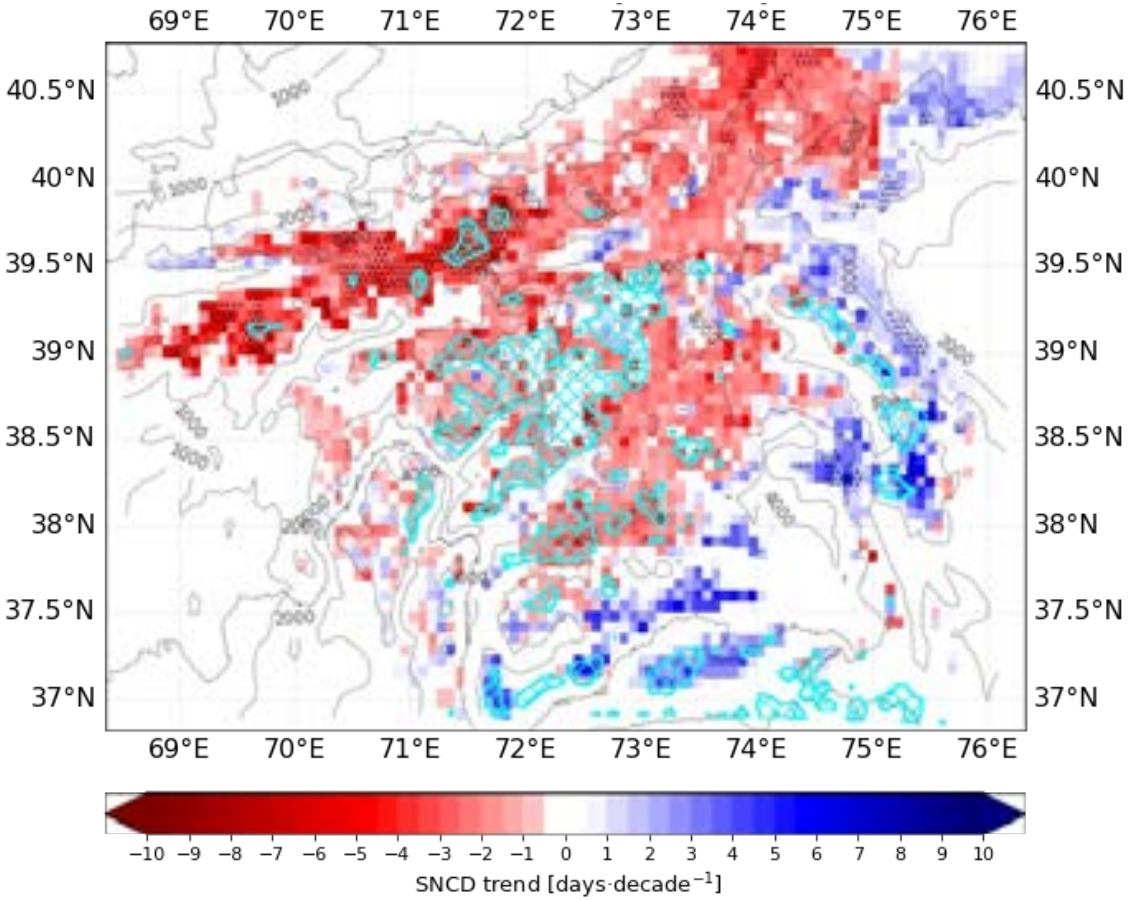
~1000 m
Winter difference
MAR higher in Pamir

Lower seasonal amplitude
Less pronounced in Central Himalaya

ESA-CCI
Winter anomaly
Unusually low snowline in Pamir

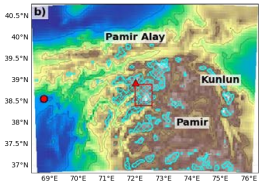
Trend of snow cover duration (1950-2025)

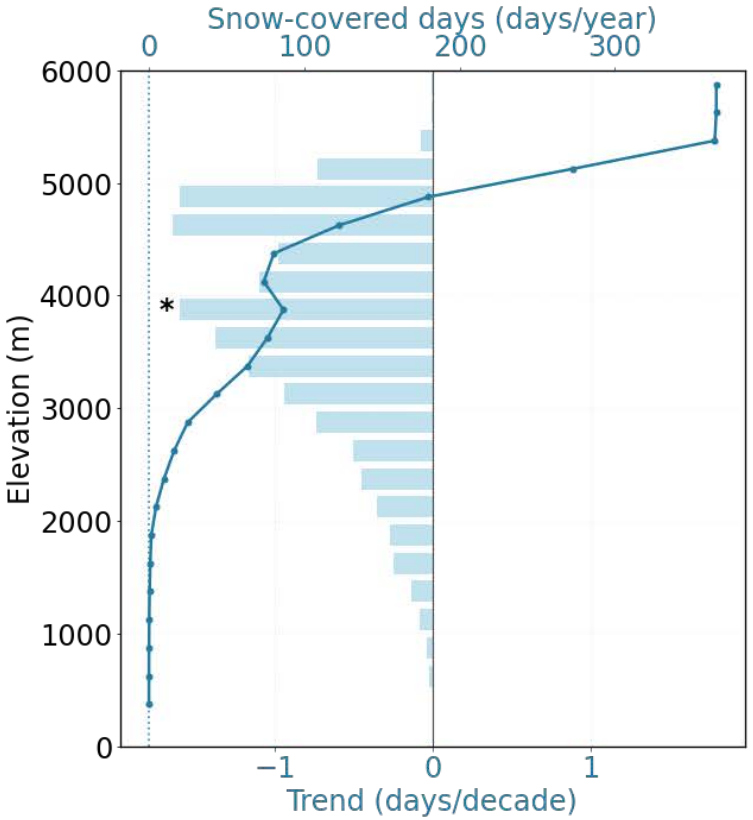
Trend of snow cover duration (1950-2025)



Significant reduction
of ~1 week / dec

Annual climatology and trends by elevation (1950-2025)





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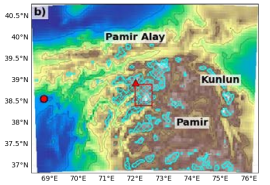
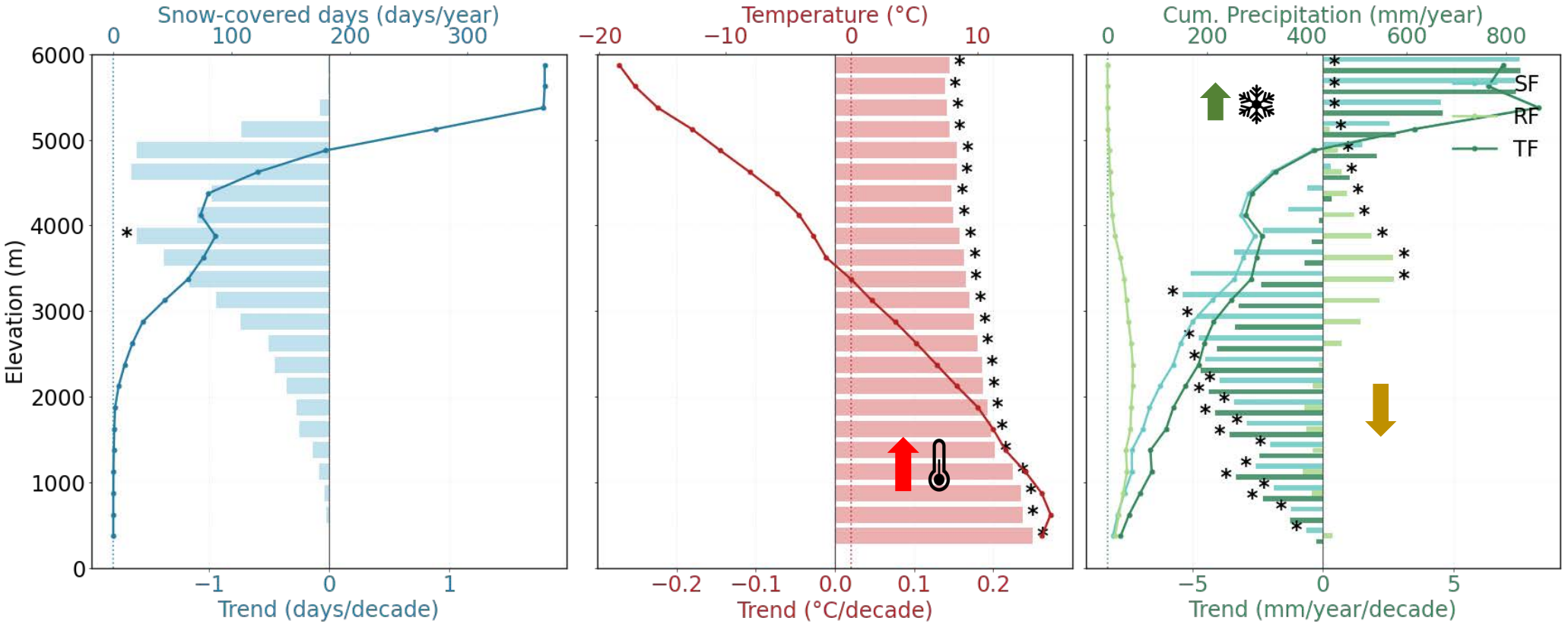


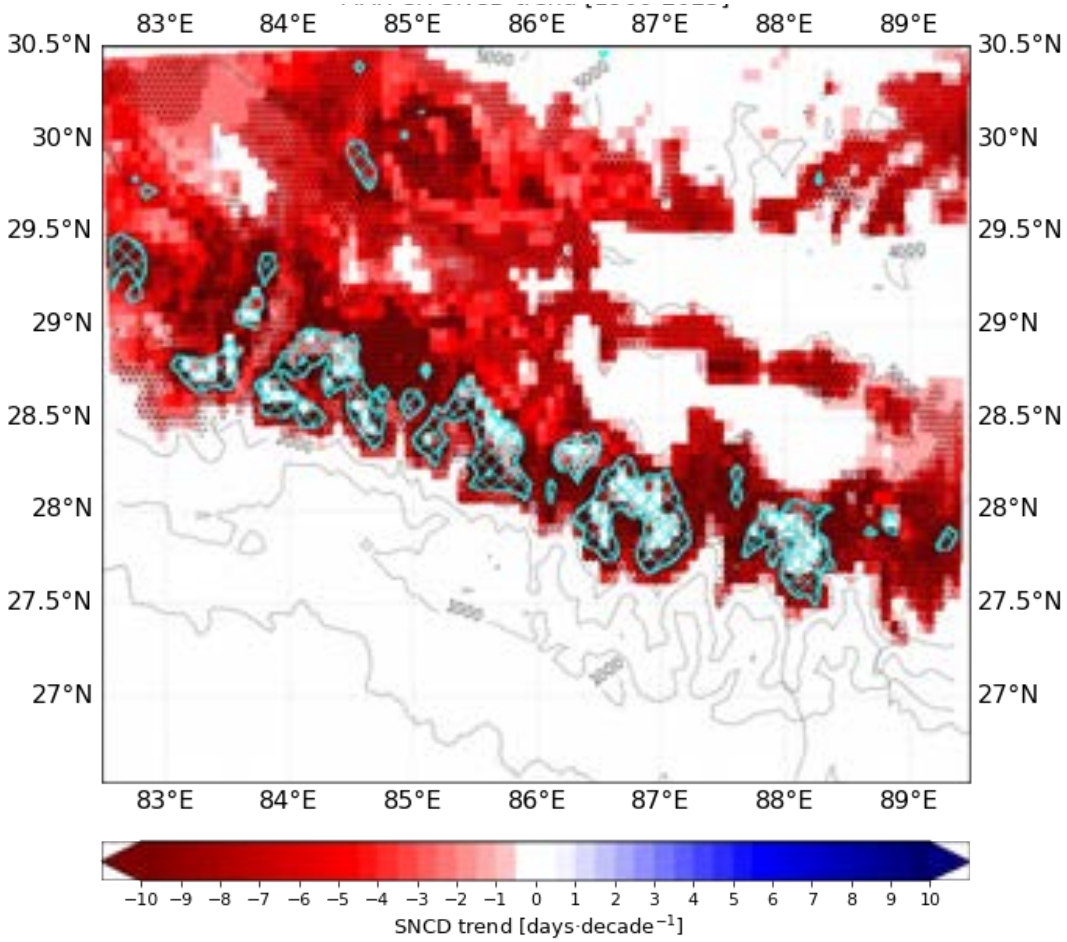


Not significant decrease

Less (*more*) warming at high (*low*) elevations

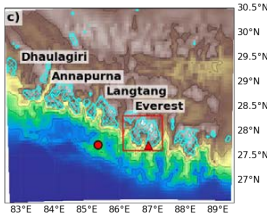
Increase at high elevation
Decrease at mid-low elevation

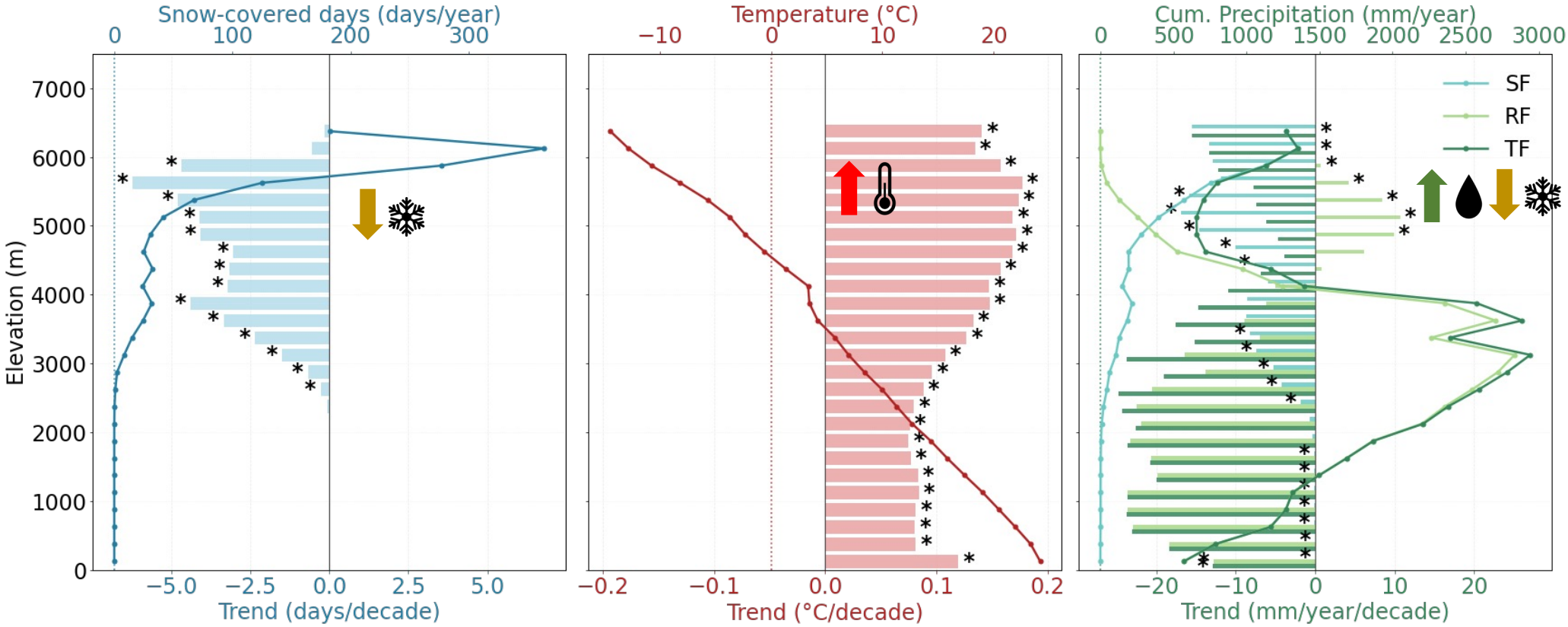
Trend of snow cover duration (1950-2025)



Significant reduction of
~ 10 days / dec

Annual climatology and trends by elevation (1950-2025)





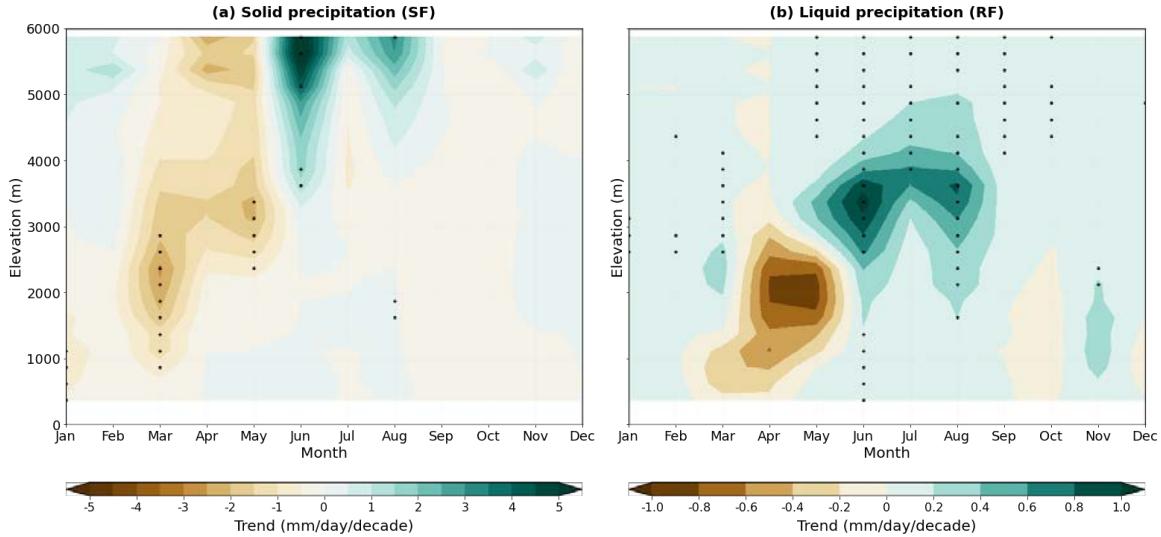
Strong significant decrease

More (*less*) warming at high (*low*) elevations

Increase liquid vs decrease solid at high elevation

Annual cycle of trends by elevation (1950-2025)

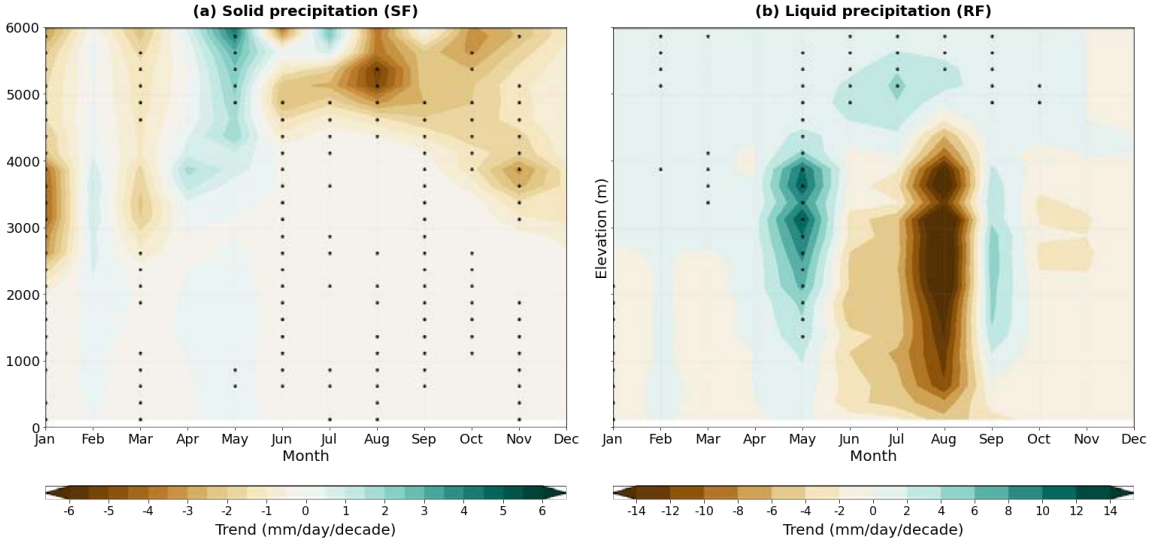
Pamir



Decrease in accumulation season

Increase in melting season

Central Himalaya



Shift in monsoon

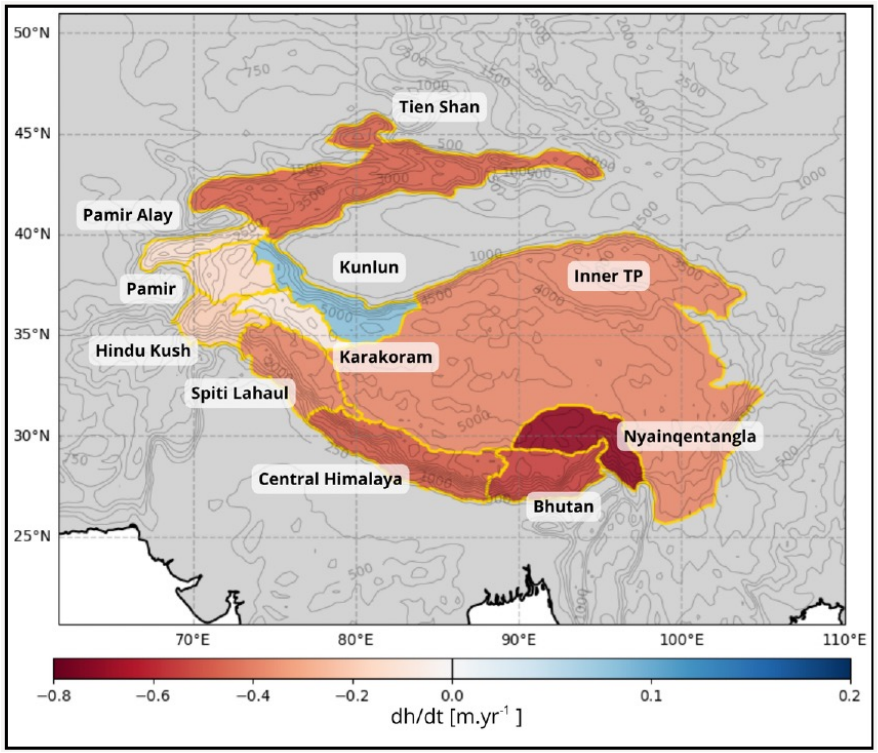
Increase in premonsson
Decrease in JA

BUT **increase** in ON notably at hight elevations

Glacier elevation changes (2000-2019)

Glacier elevation changes (2000-2019)

Brice et al, *in prep*



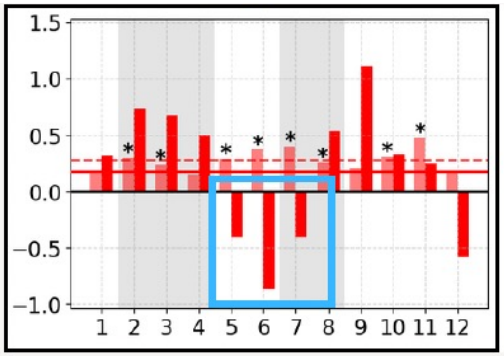
Glacier elevation changes (2000-2019)

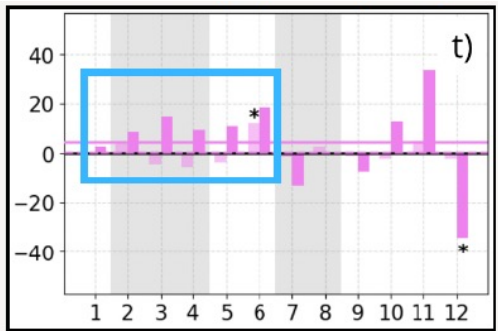
Karakoram $\frac{dh}{dt}$ = -0.073 m/yr

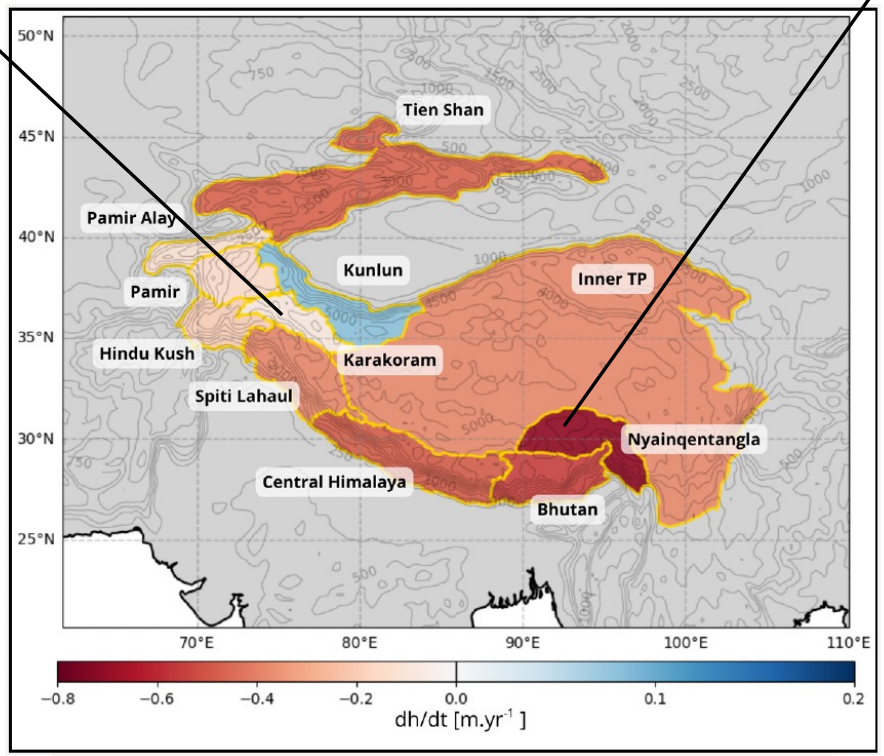
Nyainqentangla $\frac{dh}{dt}$ = -0.704 m/yr

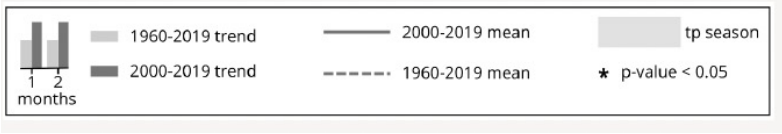
t2m [°C/dec]

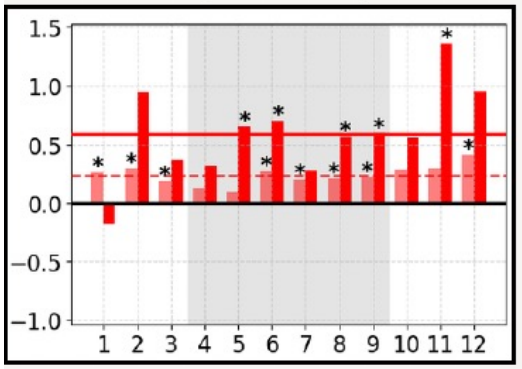
sf [%/dec]

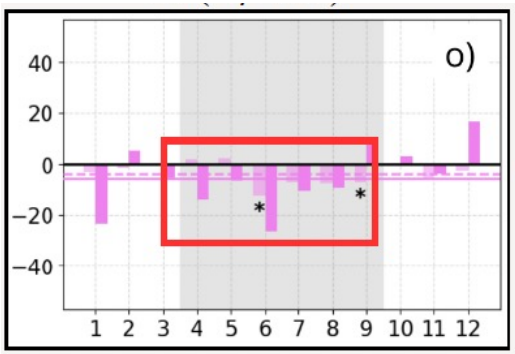












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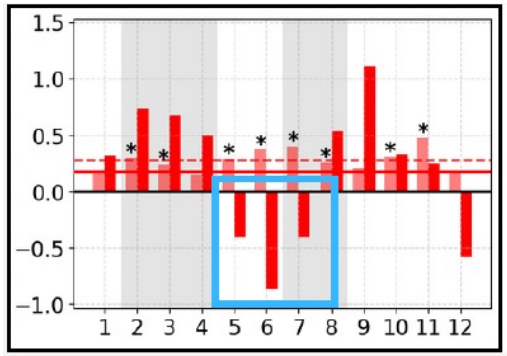
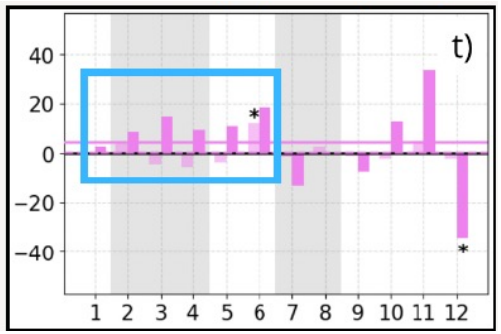
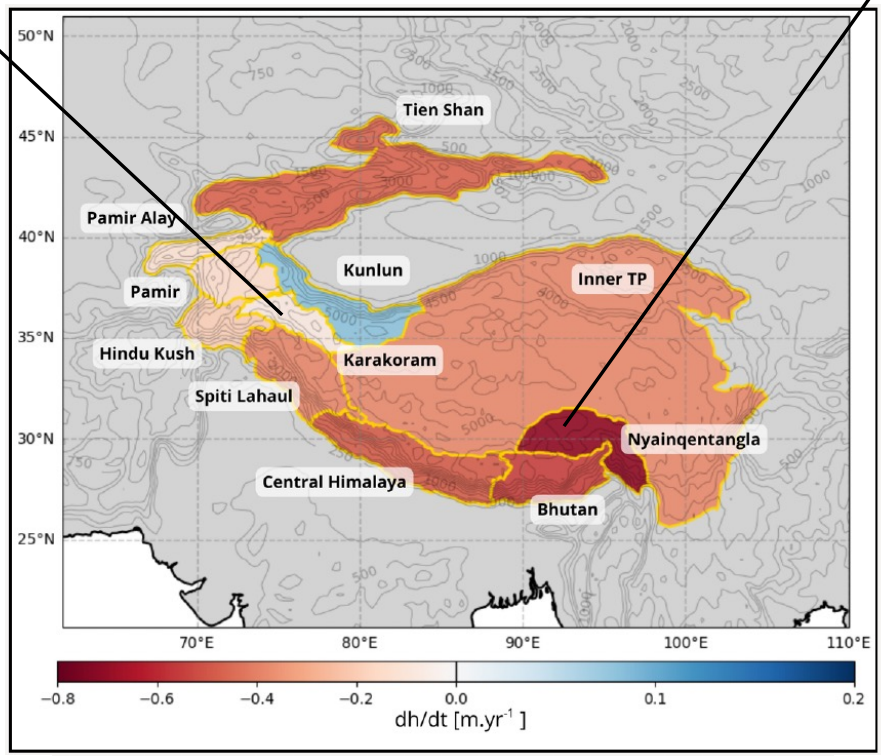
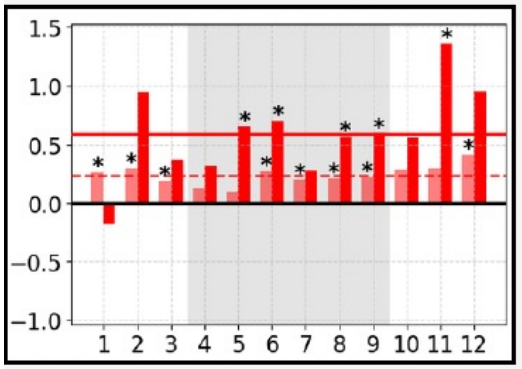
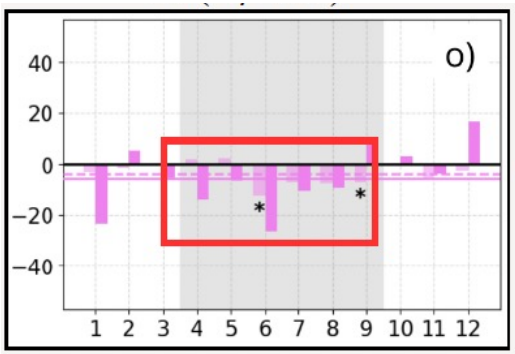
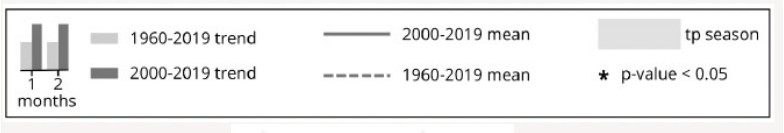














Internal climate variability
Decadal / Multi-decadal

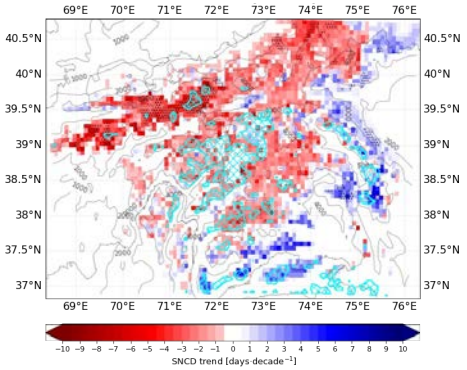
Strong Recent warming

Conclusion

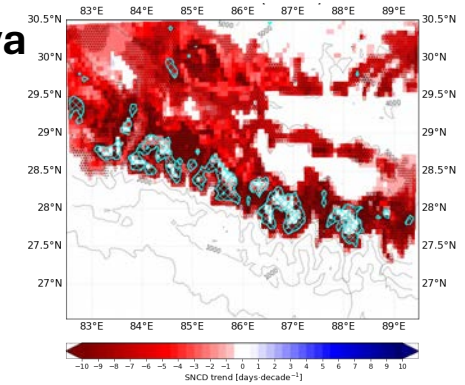
Q1: MAR vs observation

Q2: Snow trends (1950-2025)

Pamir



Central Himalaya



Snow cover duration	~ - 2.42 days/dec (mean) ~ - 8.0 days/dec (max)	~ - 2.32 days/dec (mean) ~- 10 days/dec (max)
Elevation Dependent Climate Changes	Stronger warming at low elevation Solid precipitation increase at high elevation	Stronger warming at high elevations Liquid precipitation increase, solid precipitation decrease
Rain-snow transition	+ 30.3 m/dec	+ 24.6 m/dec
Precipitation changes	Dominated by internal variability	Changes associated with monsoon onset/offset shifts

Happy to share! zenodo **HMA simulations 7kmx7km (1950-2025)**

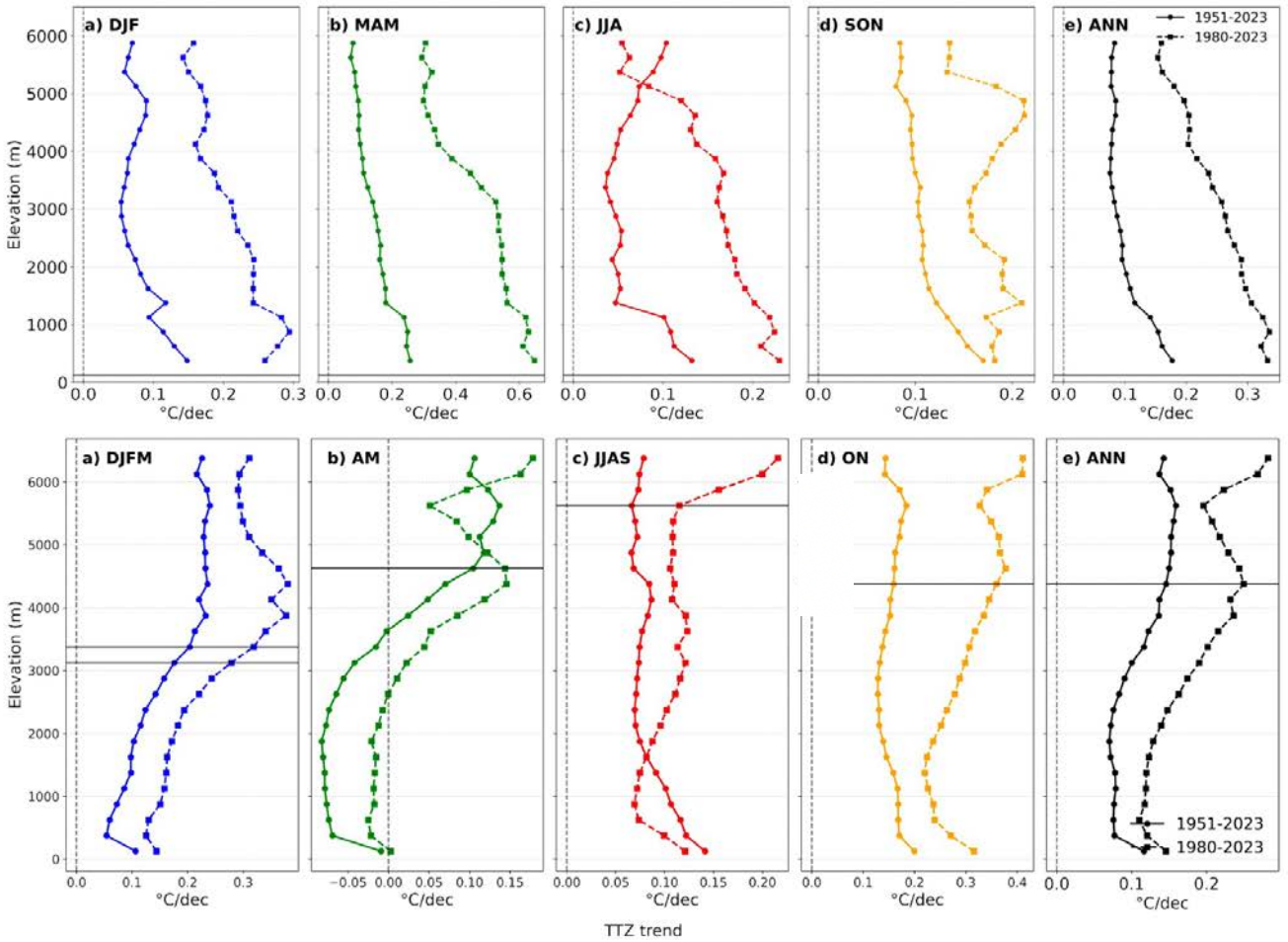
maria.santolaria-otin@univ-grenoble-alpes.fr

Back slides

Temperature trend by elevation: long vs recent period

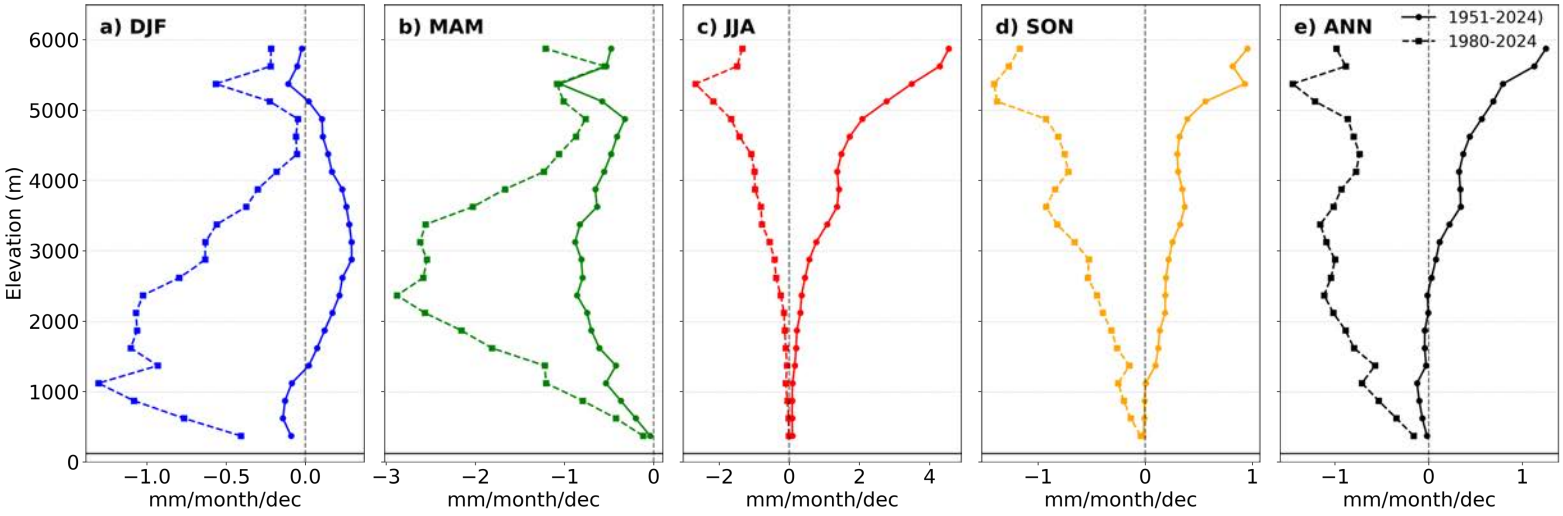
Pamir

Central Himalaya

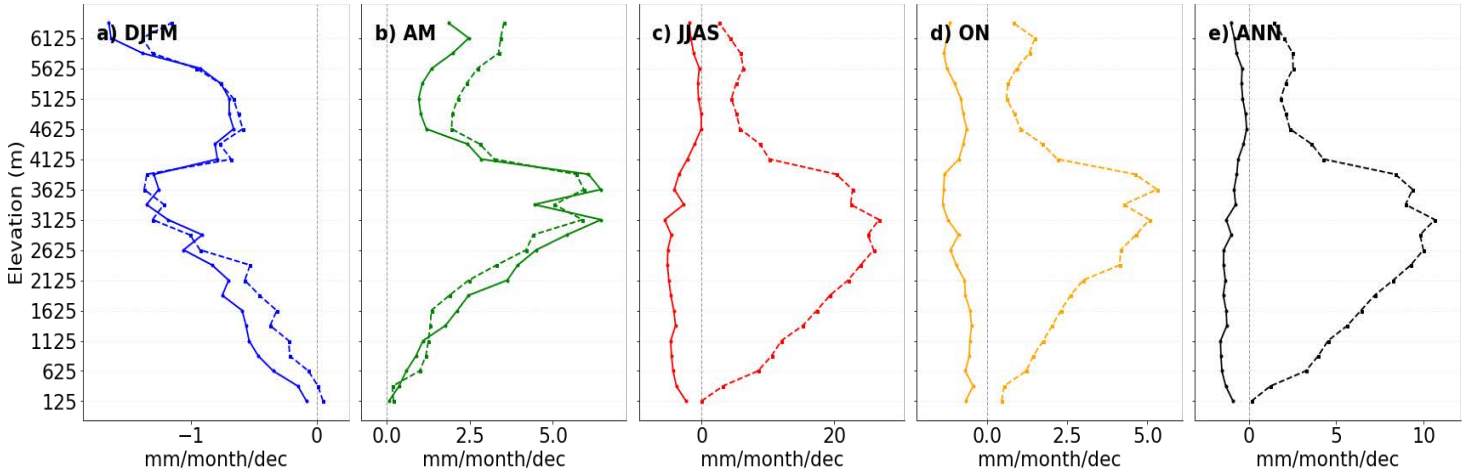


Precipitation trend by elevation: long vs recent period

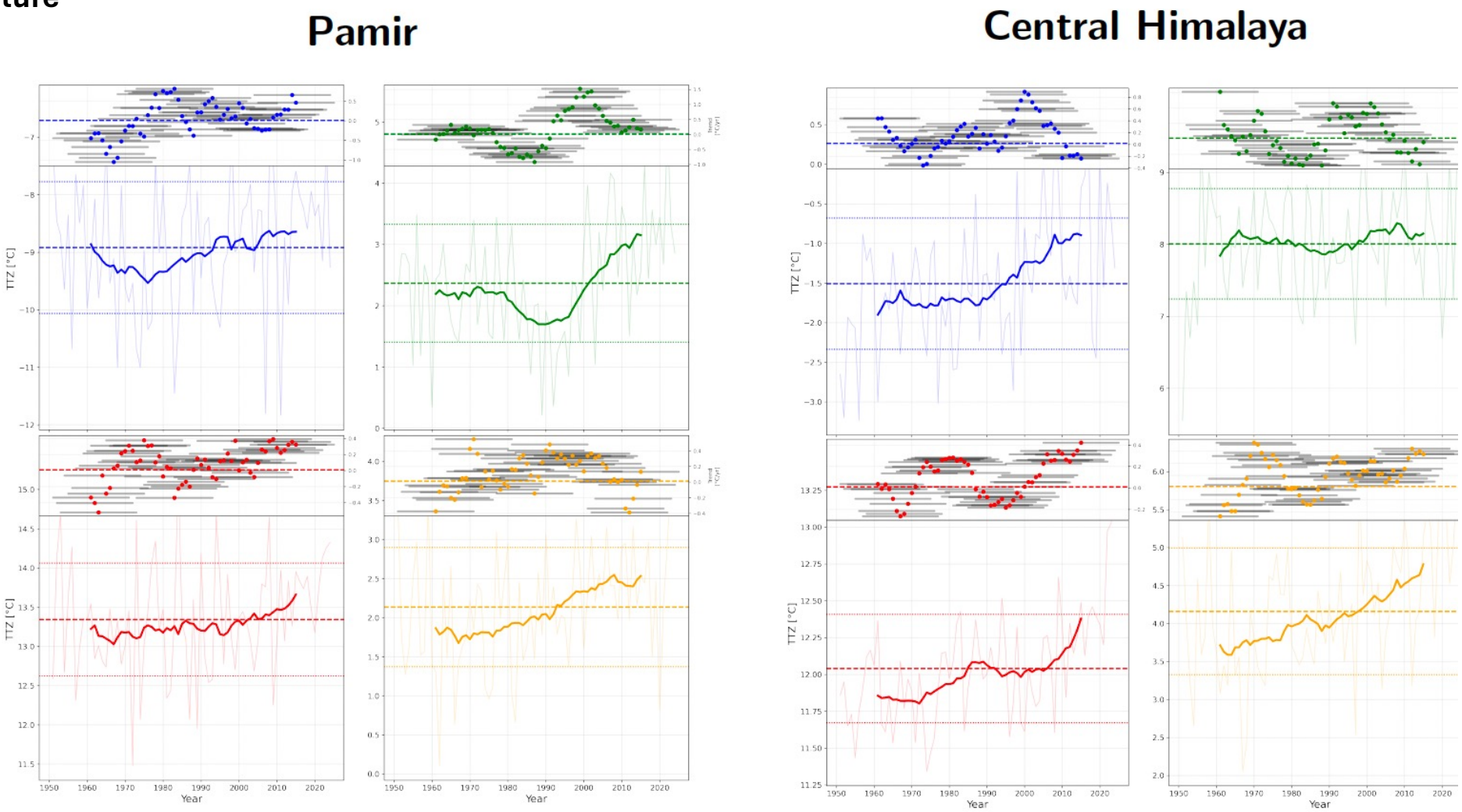
Pamir



Central Himalaya

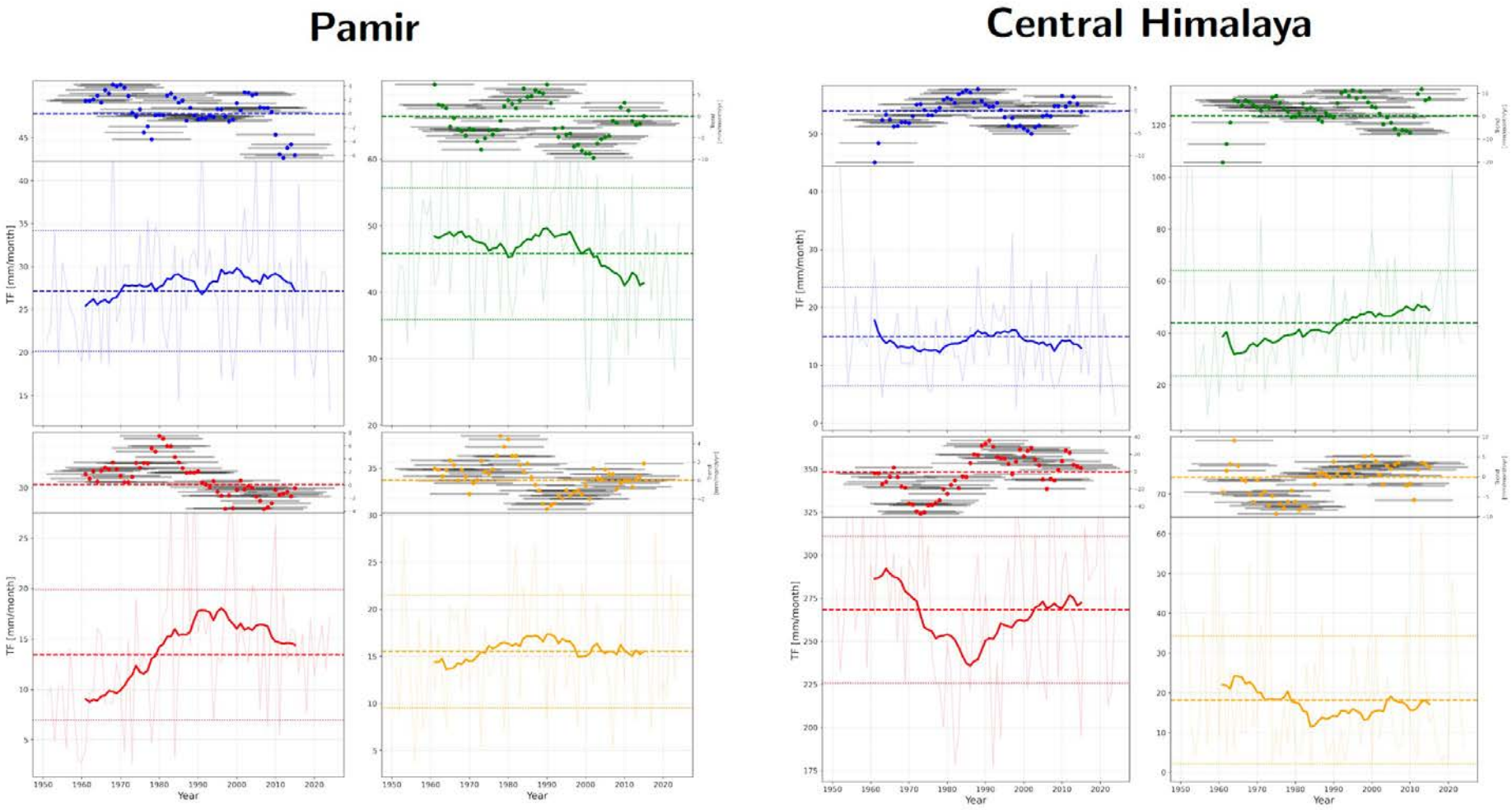


Temperature



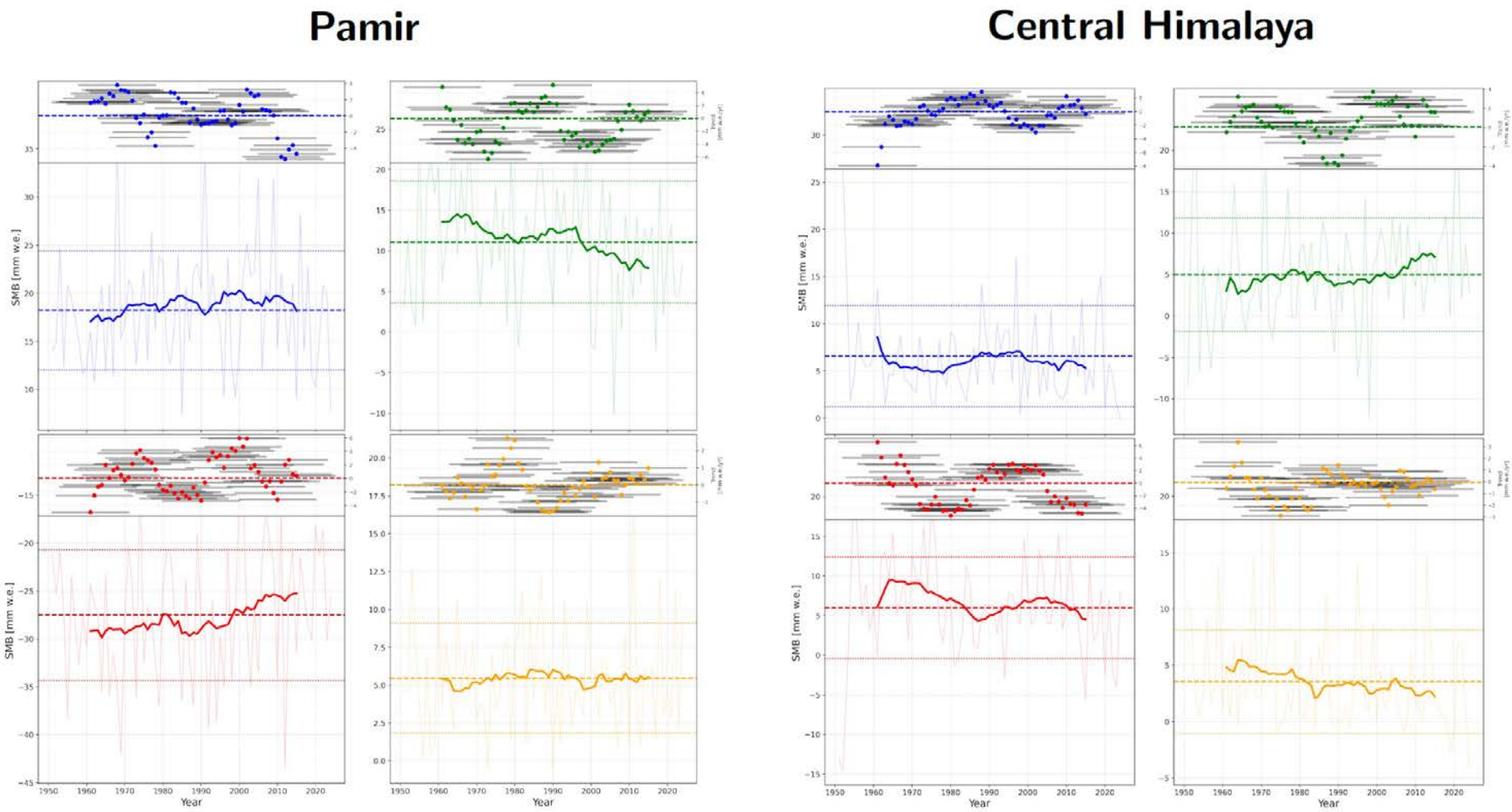
Seasonal rolling mean (solid) and trend (dots) of 20 years time series 1950-2025

Precipitation



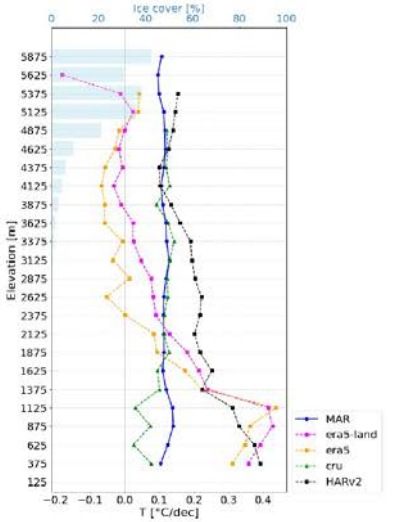
Seasonal rolling mean (solid) and trend (dots) of 20 years time series 1950-2025

Surface Mass Balance



Seasonal rolling mean (solid) and trend (dots) of 20 years time series 1950-2025

vertical_profile_elevation_T2M_trend.MAR_multiobs_DJF_1980-2020_GRp



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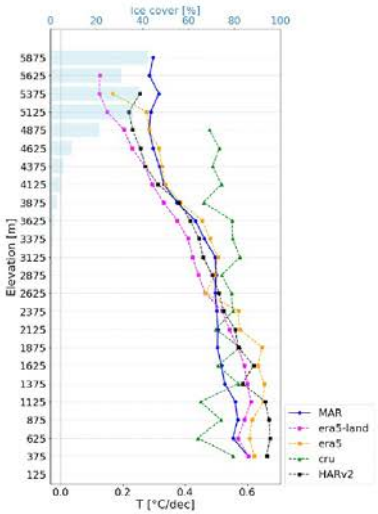

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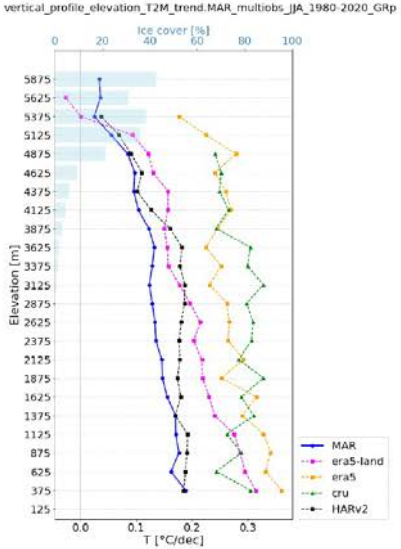

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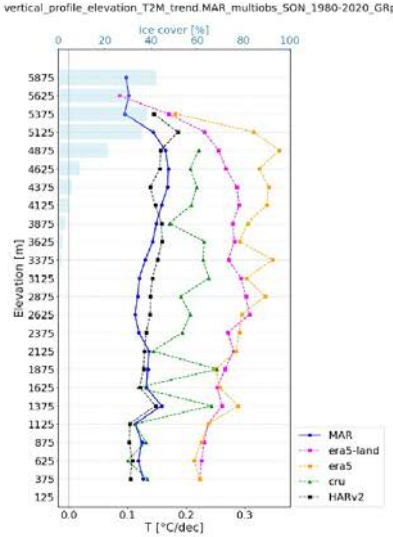

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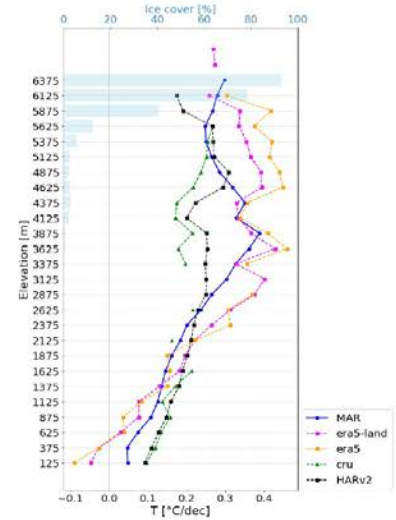

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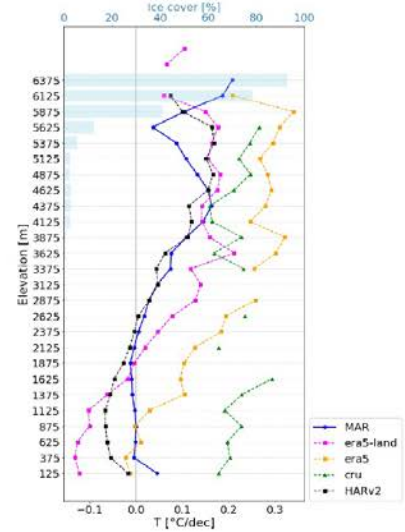

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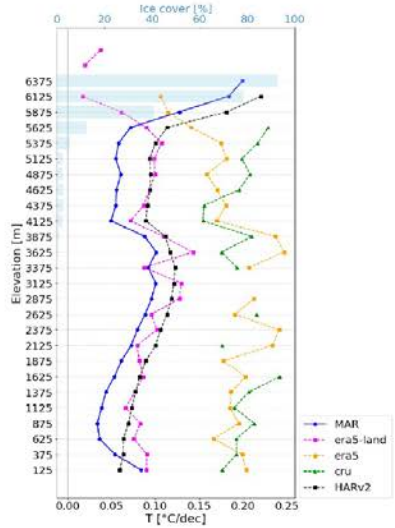

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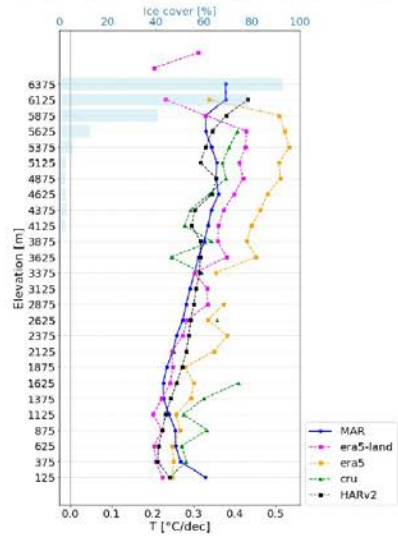
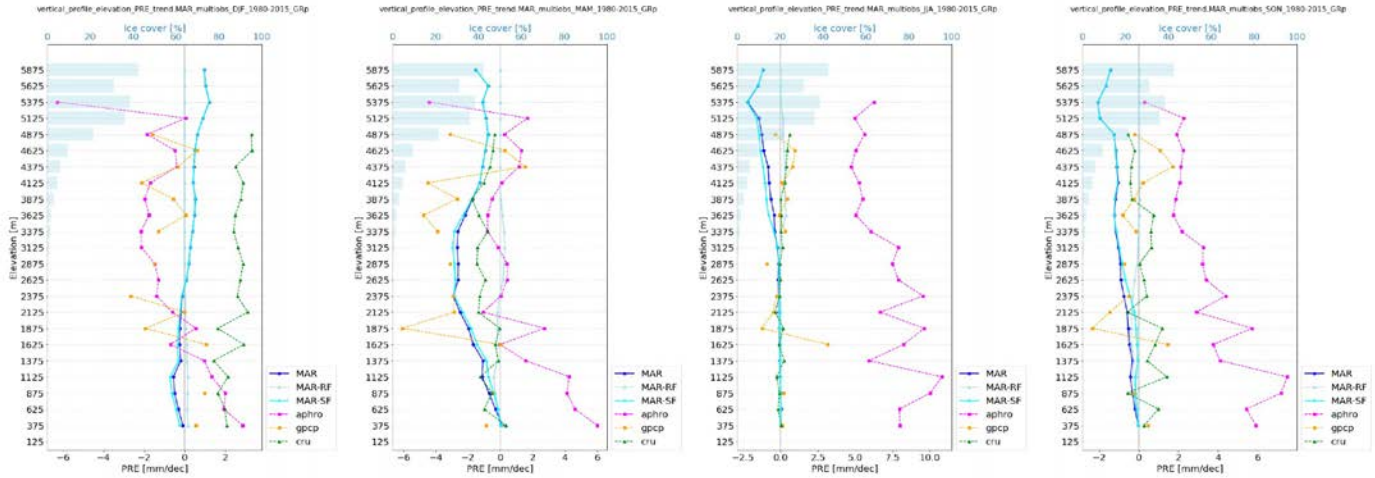
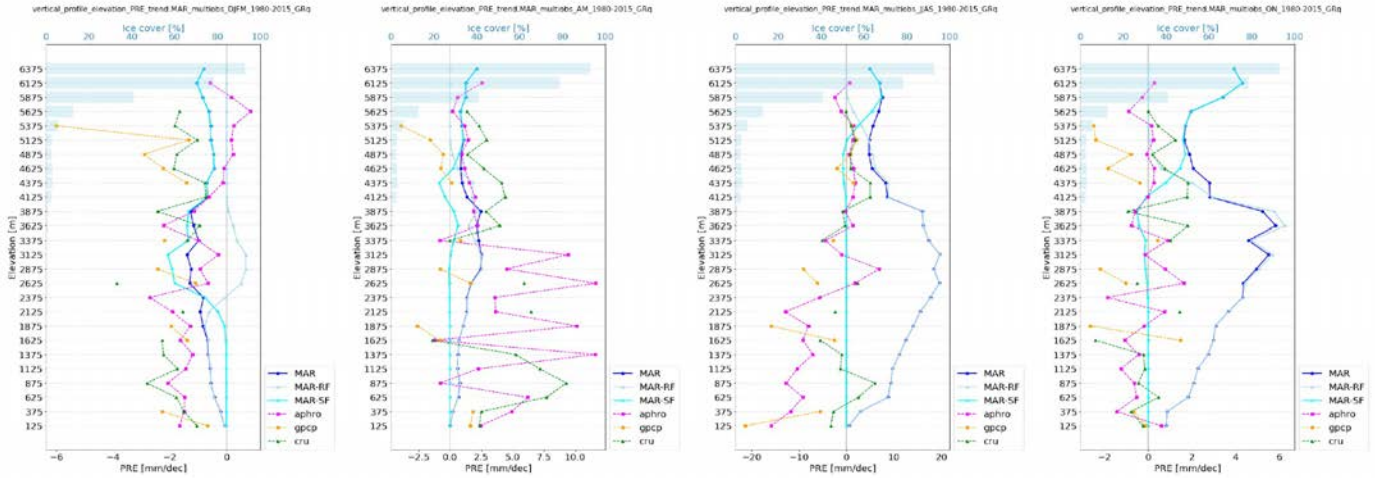


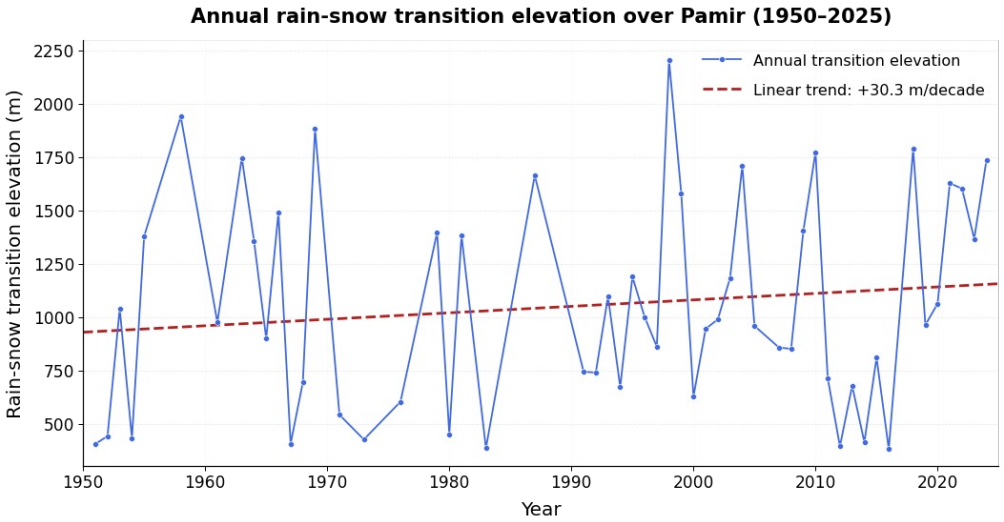
GRp (Pamir)

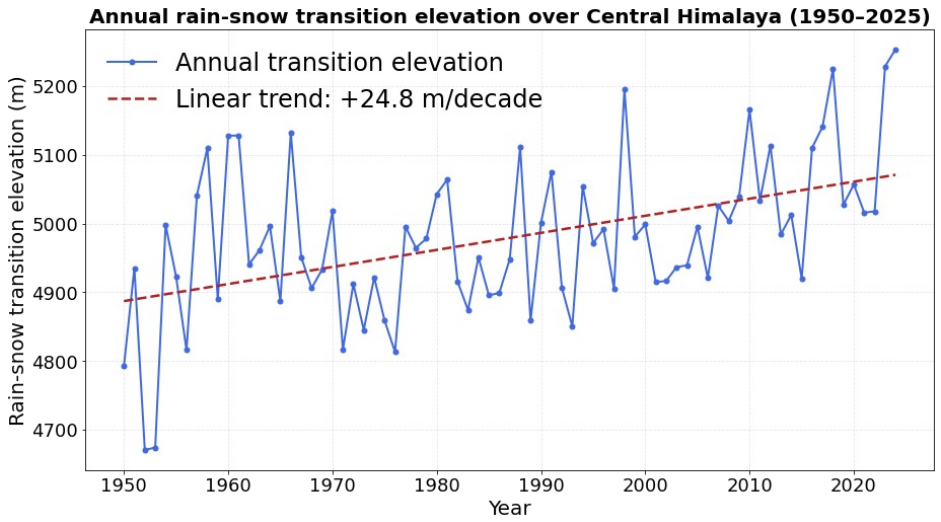


GRq (Central Himalaya)



Rain-snow transition:





Scripts

- https://github.com/msantolariaotin/MAR-RECAP/tree/main/2026-11-13_atelierneige_snow
- https://github.com/msantolariaotin/MAR-RECAP/blob/main/2026-11-13_atelierneige_snow/atelierneige_snow_cover_duration_GRq_fig1_spatial.ipynb
- https://github.com/msantolariaotin/MAR-RECAP/blob/main/2026-11-13_atelierneige_snow/atelierneige_snow_cover_duration_GRp_fig1_spatial.ipynb
- https://github.com/msantolariaotin/MAR-RECAP/blob/main/2026-11-13_atelierneige_snow/aterlier_neige_clim_vertical_CentralHimalaya.ipynb
- https://github.com/msantolariaotin/MAR-RECAP/blob/main/2026-11-13_atelierneige_snow/aterlier_neige_clim_vertical_Pamir.ipynb

References figures

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- Ménégoz,et al encyclopedie
- Brice et al, in prep o stage
- Palazzi, et al, 2013
- Bonekamp et al, 2018 https://doi.org/10.1175/JHM-D-17-0212.1